MIKE 21 Modeling System

The MIKE 21 system is a two-dimensional software package that was developed by the Danish Hydraulic Institute Water & Environment. The MIKE 21 system is comprised of four main groups of numerical models. They are hydrodynamic, sediment process, wave, and environmental hydrodynamic models. In the context of the National Flood Insurance Program (NFIP), the hydrodynamic and wave model groups of the MIKE 21 system are relevant to the types of physical processes considered in floodplain mapping and are the only model groups that are accepted by the Federal Emergency Management Agency (FEMA) for NFIP usage. The sediment process models of MIKE 21 are used to simulate shoreline change and sand transport, which are not currently considered in Flood Insurance Studies. The environmental hydrodynamic models of MIKE 21 are used to examine water quality issues and, thus, are not pertinent to the NFIP.

Hydrodynamic Module

The hydrodynamic model (MIKE 21 HD) is the central model of the MIKE 21 system. It serves as the basis for most of the other models within the system; for example, it provides the basis for sediment transport studies. The MIKE 21 HD model is versatile enough to represent a variety of different systems, such as oceans, lakes, estuaries, and rivers. To do this, the MIKE 21 HD model simulates water-level fluctuations and flows resulting from a variety of forces. The water levels and flows are determined by solving the full time-dependent nonlinear equations of continuity and conservation of momentum on a rectangular finite difference grid using an alternating direction implicit scheme of second-order accuracy. The equations account for the effects of convective and cross momentum, bottom shear stress, wind sheer stress, barometric pressure gradients, Coriolis force, momentum dispersion, wave-induced currents, evaporation, sources and sinks, and flooding and drying. The solution results in water levels and velocities in the x and y directions over the entire computational domain.

The MIKE 21 HD model is calibrated using three parameters: bed resistance, wind friction factor, and the momentum dispersion coefficient. The accuracy of the model is determined more by the quality of the setup data rather than the variations in the calibration coefficients. Setup requires bathymetry, boundary conditions (water level or flow data), initial conditions (water-surface elevations of flux densities), meteorological data, and initial values for the calibration coefficients.

The MIKE 21 HD and Nested Hydrodynamic (NHD) models are accepted for NFIP coastal storm surge analyses. The MIKE 21 HD model:

- Supports wave input into hydrodynamic models; wave setup can be directly included in MIKE 21 HD simulation.
- Provides direct grid resolution to provide sufficient detail to define most coastal features.
- Uses an efficient and well-proven flooding and drying algorithm.
- Provides a dynamic nesting option in the NHD model.
- Generalized for the simulation of synthetic or historical storms (hindcasting).

- Provides over 100 Graphic User Interface-driven service programs and Geographic Information System links to reduce setup time and aid in analysis and presentation.
- Provides calculations of special flood-related quantities, such as peak water levels evaluated on a time-step basis at each grid point, as well as the duration at which water levels are above prescribed levels.

MIKE 21 HD cannot always be applied in a similar manner that FEMA Surge is now commonly applied (e.g., for performing a large range of synthetic hurricane simulations where the synthetic hurricane is based on the Joint Probability Method). Areas of particularly complex topography and/or areas with small geometric features, if significant to the propagation of the surge, may be more appropriately handled by FEMA Surge. However, many geometric features are resolvable by MIKE 21 HD either directly or via geometrical parameterization. MIKE 21 HD can also be used to verify the 1% annual chance flood elevation calculated by FEMA Surge by hindcasting an extreme storm on record.

Wave Module

There are five wave models contained in the MIKE 21 system: Nearshore Spectral Wind-Wave (NSW) model, Offshore Spectral Wind-Wave (OSW) model, Parabolic Mild Slope (PMS) model, Boussinesq Wave (BW) model, and Elliptical Mild Slope (EMS) model. Only the OSW and NSW models are accepted to use for NFIP studies.

The OSW model is a spectral wind-wave growth model that can be used to dynamically simulate the waves produced by a storm. This information can then be passed to the NSW model for propagation into the nearshore zone.

The NSW model is a spectral wind-wave model that describes the propagation, growth, and decay of short-period waves in the nearshore environment. It includes the effects of refraction, shoaling, wave generation due to wind, energy dissipation due to bottom friction, and wave breaking. The basic formulation of the model is based on the conservation equation for the spectral wave action density developed by Holthuijsen. It uses the Eularian finite difference solution technique for partial differential equations followed by a once-through marching procedure to solve the non-linear algebraic equations. The results are the significant wave height, zero-crossing wave period, mean wave direction, and directional standard deviation.

The NSW model can account for roughness in propagating the wave onshore. Obstructions that cannot be defined by the grid would need to be parameterized in terms of bed roughness or bathymetry. Waves propagating into complex nearshore geometry can induce a spatially varying elevated stillwater level. The modeling of the two-dimensional inshore transformation allows for inclusion of wave setup in the hydrodynamic modeling, thereby increasing the stillwater level and affecting the wavefield.

The NSW model also calculates the radiation stress (S_{XX}, $S_{YY,}$ and S_{XY}), which can be inputted into the MIKE 21 HD module for wave setup and a variety of other analyses.

Application Examples

The MIKE 21 system has been used worldwide over the last 20 years for over 400 studies, including those in the United States. It is being used in conjunction with projects of the U.S. Army Corp of Engineers, the Bureau of Reclamation, and the National Aeronautics and Space Administration (NASA). Below are two examples of how the MIKE 21 system has been used in the United States.

Flood levels generated by hurricanes at the Kennedy Space Center, Cape Canaveral, Florida. In this study, MIKE 21 was used to predict storm surges generated by seven hurricanes for the outer coastline approaches to Cape Canaveral, including the inlets and inland waterways.

Several factors were examined to determine the total water elevation during the passage of a hurricane, including astronomical tide, storm surge generated by the wind and atmospheric pressure variations associated with a hurricane, rainfall run-off, wave setup associated with hurricane-generated waves, and local wave height conditions. The storm surge contributions from the tide, wind, and barometric pressure were determined from the MIKE 21 HD model. A total of five nested grids were used ranging from 8,100-meter to 100-meter grid spacings. Wave setup was included using a combination of the MIKE 21 OSW model and LITPACK.[1] The MIKE 21 OSW model was used to determine the offshore wave conditions generated by the hurricane winds. The results were compared to nearshore buoy measurements during the historical hurricane event and calibrated accordingly. The MIKE 21 OSW results obtained from the synthetic hurricanes were then used as offshore boundary conditions in the LITPACK model providing wave setup elevations to be included in the MIKE 21 HD boundary conditions.

Overland wave conditions were obtained using a combination of MIKE 21 NHD, OSW, and NSW models. MIKE 21 OSW provided offshore boundary wave conditions to the NSW module. The MIKE 21 NHD storm surge elevations were used to provide initial water-surface elevations in the MIKE 21 NSW model. This study was completed in Spring 2000 and has been approved by NASA officials.

Inundation maps for hypothetical dam failures by the Bureau of Reclamation. The Bureau of Reclamation selected the MIKE 21 system to use in conjunction with the National Weather Service's DAMBRK model to generate inundation maps depicting the results of hypothetical dam failure scenarios as part of the review of the agency's Emergency Action Plans for its facilities, including reservoirs and dikes. MIKE 21 has been used to model the Folsom Reservoir (right wing of Mormon Island and six dikes), San Luis Reservoir and O'Neill Forebay, San Justo Reservoir and Dike, Monicello Dam, New Melones Dam, Phoenix Reach 11 Dike System, and Claire Hill Whiskeytown Reservoir. Although none of the applications is for coastal analyses, the Bureau obtained satisfactory results from MIKE 21 modeling and plans on continuing to use it for at least 15 more major studies.

[1] LITPACK is a system of several numerical models developed by the Danish Hydraulic Institute Water & Environment. The LITPACK models focus on one-dimensional (i.e., cross-sectional description) littoral processes. LITPACK is not an accepted model for NFIP usage.